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FATIGUE TESTS OF CONNECTION ANGLES

BY

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AND

JOHN V. COOMBE



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BY

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FATIGUE TESTS OF CONNECTION ANGLES

I. INTRODUCTION

1. *Object and Scope of Investigation.*—The stringers of through-truss railway bridges are connected to the floor beams by means of connection angles. The primary function of these connection angles is to transmit the end shear from the stringer to the floor beam but, because they are riveted to both the stringer and the floor beam, the angles are subject to flexural stresses due to the deformation of other portions of the structure. There are two actions that contribute to these flexural stresses: (1) The bottom chord of the truss changes in length due to a change in the chord stress resulting from the passage of a train. There is not a corresponding change in the length of the stringers and, since the floor beam is connected to both the chord and the stringers, the floor beam is subjected to a transverse horizontal flexure which produces in each stringer an axial force which pulsates and which is transmitted through the connection angles. The magnitude of the force depends on the magnitude of the change in the chord stress, on the stiffness of the floor beams, and on the distance between stringer expansion joints. (2) The stringers deflect vertically because of the wheel loads, and this deflection rotates the end of the stringer and subjects the connection angles to a moment in the plane of the stringer web.

The effect of the elongation of the bottom chord of a through-truss bridge is to bend the outstanding leg of the connection angles, as shown in Fig. 1, over their entire depth. There is one complete stress cycle for each passage of a train. The effect of the flexure of the stringer is to bend the outstanding leg of the connection angles at the top, but the deflection decreases as the distance from the top of the angle increases; the law governing the change is not known. There is one complete cycle for the passage of each wheel or group of wheels.

There are three features relative to the flexure in the outstanding legs of the connection angles that are worthy of attention: (1) The flexural stress in the angles varies from near zero to a maximum a large number of times during the life of a bridge, so that the problem is one of fatigue. (2) The flexural stress in the angles is incidental, and contributes little, if any, to the support of the load, so that, if the connection were so constructed as to permit the movement without producing stress, the primary function of the connection would not be impaired. (3) The rivets in the outstanding legs of the connection

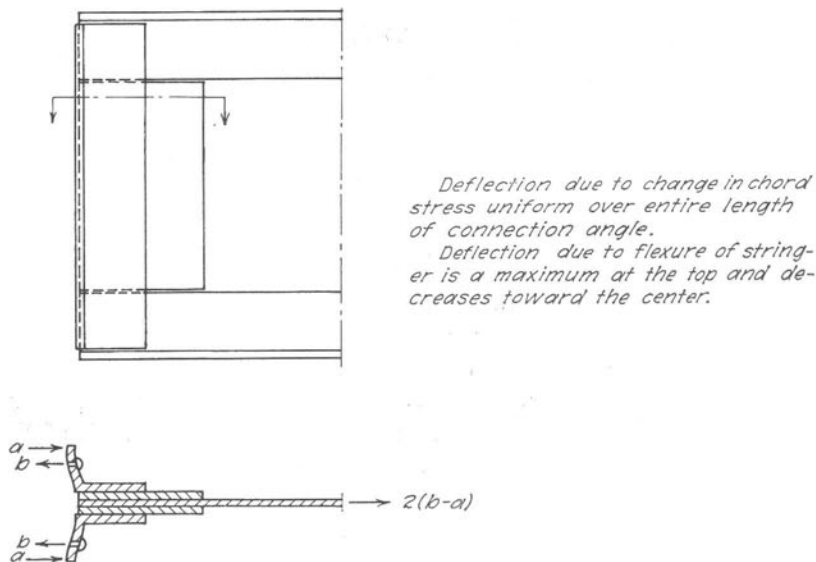


FIG. 1. FLEXURE OF CONNECTION ANGLES FOR STRINGERS

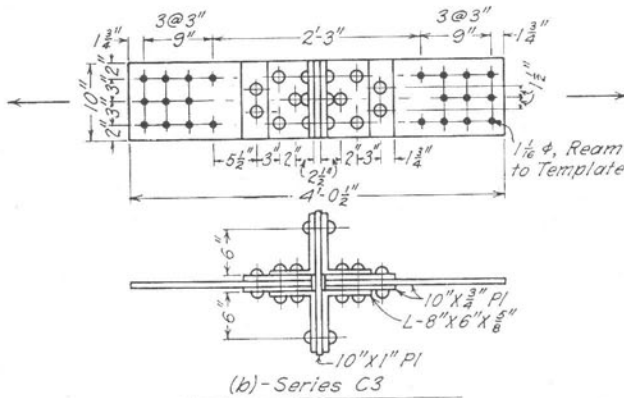
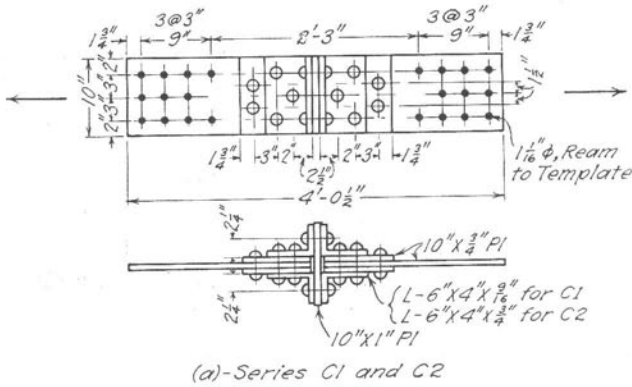
angles are subjected to tension, and the force that bends the outstanding leg of the angles, which is parallel to the direction of the tension in the rivets, fluctuates.

Neither the flexibility of the outstanding leg of a connection angle, nor the fatigue strength of the angle leg or of the rivets connecting the angles to the floor beams, can be determined by rationalization. The tests described in this paper were therefore planned to *determine the magnitude of the deflection* to which the outstanding leg of a connection angle can be subjected a large number of times without failure of either the angle or the rivets.

2. *Acknowledgments.*—The specimens used in these tests were contributed by the American Bridge Company and the tests were made in the fatigue testing machines built in connection with the investigation to determine the fatigue strength of riveted joints reported in University of Illinois Engineering Experiment Station Bulletin No. 302.

The tests were made in the Arthur Newell Talbot Laboratory and the direct expenses of the tests were paid from funds provided by the University.

This investigation has been carried on as a part of the work of the Engineering Experiment Station, of which Dean M. L. Enger is the director, and of the Department of Civil Engineering, of which Prof. W. C. Huntington is the head.



Rivets lin. diam. Holes $1\frac{1}{16}$ in. subpunched and reamed.
Rivets driven with hydraulic riveting machine.

FIG. 2. DETAILS OF SPECIMENS

II. DESCRIPTION OF TESTS

3. *Description of Specimens and Tests.*—Nine specimens were tested, three series of three specimens each, C1, C2, and C3. All specimens were similar, each one consisting of two central plates, four filler plates, four angles, and a spacer, as shown in Fig. 2. The spacer corresponds to the plate and fills of a floor-beam web, and the other parts correspond to the connection angles, fills, and web plate of the stringers. Each specimen may therefore be considered as a short length of the connection between the stringers and a floor beam to which they are connected together with a portion of the floor-beam web included. The central plates had $1\frac{1}{16}$ -in. holes at the ends for bolting the specimen to the pulling heads of the 200 000-lb. fatigue

testing machines. All rivets were of 1 in. nominal diameter, and the grip of the rivets was as follows: for series C1, $2\frac{1}{8}$ in., for series C2, $2\frac{1}{2}$ in., and for series C3, $2\frac{1}{4}$ in.

The action of the testing machine was to subject the specimen to an axial force, parallel to the longitudinal axis of the stringer, that varied from zero to a maximum tension, thereby subjecting the outstanding legs of the connection angles to a moment that varied from zero to a maximum. That is, the testing machine subjected the connection angles of the specimen to the same kind of a stress cycle as the connection angles of through-truss bridges are subjected to as a result of the change in stress in the chord that occurs with each passage of a train. Moreover, this action approximates closely the action to which the tops of the connection angles of a bridge are subjected with the passage of each group of axles because of the deflection of the stringers.

The three specimens of each series were geometrically identical, within the limitations of standard shop practice, and the series differed only in the size of the connection angles and in the length of the rivets. For the C1 series the angles were 6 in. x 4 in. x $\frac{9}{16}$ in., short legs out; for the C2 series they were 6 in. x 4 in. x $\frac{3}{4}$ in., short legs out; and for the C3 series they were 8 in. x 6 in. x $\frac{5}{8}$ in., long legs out. There were 4 rivets in tension for the specimens of series C1 and C2, and 6 rivets in tension for the specimens of the C3 series.

The specimens were fabricated from standard carbon structural steel angles and plates, and the rivets were from standard carbon-steel rivet stock.

During a test the stress, which varied from zero to a maximum tension, was applied at the rate of 180 cycles per minute. The maximum load during the stress cycle was purposely different for each of the three identical specimens of a group.

Strain-gage holes were drilled in the ends of the angles, as shown in Fig. 3, for the purpose of measuring the deflection of the angles as the load was applied. Also the tension rivets were fitted with hardened steel pins through the heads* for the purpose of measuring the change in length of the rivets as a means of determining the change in the tension. Deflection and rivet-elongation readings were taken at zero and maximum loads at the beginning of a test, and once daily throughout the test, the machine being cranked by hand while the readings were being taken.

4. *Definition of Fatigue Strength.*—The term fatigue strength of

*See University of Illinois, Engineering Experiment Station Bulletin No. 210, p. 13.

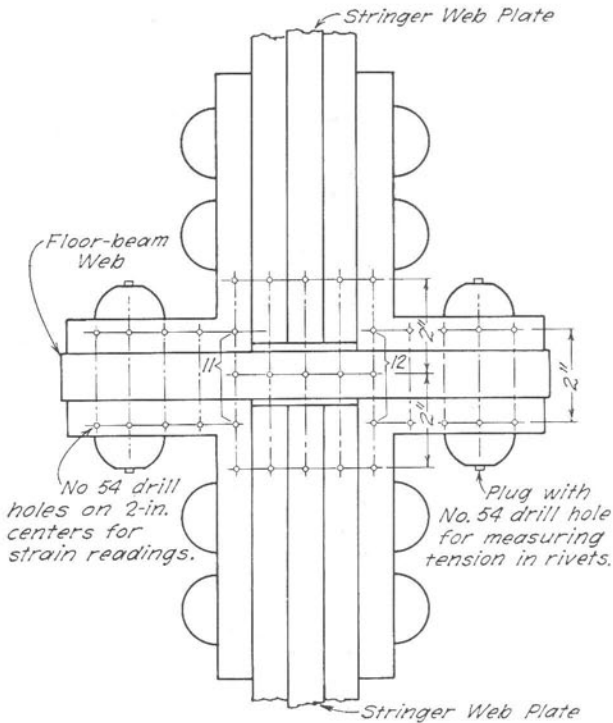


FIG. 3. TYPICAL LAYOUT OF STRAIN-GAGE HOLES AND PLUGS FOR MEASURING TENSION IN RIVETS

the connections, as used in this paper, has been arbitrarily defined as the maximum stress in the stress cycle which will cause failure at 2 000 000 repetitions, the stress in the cycle varying from zero to a maximum. It is apparent that it would be impossible to select a stress cycle such that failure would really occur at 2 000 000 cycles. It was therefore necessary to estimate the stress that would produce failure at 2 000 000 cycles from tests for which failure occurred at other than 2 000 000 cycles. The obvious method to follow would be to make a number of tests at various stresses and, from the results of those tests, draw a curve showing the relation between the maximum stress in the stress cycle and the number of cycles for failure, and, from this curve, determine the stress that would produce failure at 2 000 000 cycles. The difficulty with this method is that fatigue tests, especially of complex specimens such as a riveted joint, are erratic, and several tests are necessary to determine a curve. Moreover, the tests are expensive and funds were not available for the number of tests neces-

TABLE 1
FATIGUE STRENGTH OF CONNECTION ANGLES
Stress cycle, zero to tension

Specimen Number	Maximum Load in Terms of Average Tension in the Rivets lb. per sq. in.	Flexural Stress in Angle lb. per sq. in.*	Variation of Tension in Rivet During Cycle lb. per sq. in.		Deflection of Two Angles During Cycle in Inches†		Number of Cycles for Failure	Fatigue Strength		Part That Failed
			At Beginning of Test 4	Near End of Test 5	At Beginning of Test 6	Near End of Test 7		Rivet	Angle	
C1-1.....	18 000	46 200	6 200	12 300	0.0088	0.0218	392 000	15 300	39 250†	Rivet Angle No Failure
C1-2.....	15 000	39 000	4 520	1 700	0.0054	0.0068	2 305 500	15 200†	39 560	
C1-3.....	16 000	41 500	3 670	2 260	0.0069	0.0081	3 245 000	16 800†	43 560†	
C2-1.....	30 000	38 700	7 200	5 250	0.0248	0.0374	12 200	18 000	23 240†	Rivet Rivet Rivet
C2-2.....	20 000	25 800	1 680	3 600	0.0024	0.0031	2 961 200	20 800	26 830†	
C2-3.....	25 000	32 300	1 200	3 600	0.0044	0.0077	267 700	20 450	26 410†	
C3-1.....	7 420	73 200	5 600	1 860	0.1096	0.1120	89 200	5 667†	53 630	Angle Rivet No Failure
C3-2.....	5 920	58 800	2 270	1 350	0.0751	0.0812	259 000	4 825†	48 530	
C3-3.....	4 250	42 000	270	350	0.0498	0.0491	3 119 400	4 445†	43 900†	

*For rivet that failed, or average for all rivets if none failed.

†Average from gage lines 11 and 12 for the two ends, four gage lines in all (see Fig. 3).

‡Fatigue strength equals or exceeds this value; part did not fail.

§The flexural stress was computed from the total load on the basis that the action of the angles was as indicated in Fig. 4.

sary with this method. Other fatigue tests* indicate that the empirical formula $F = \frac{S N^{0.10}}{2\,000\,000^{0.10}}$ gives the fatigue strength corresponding to failure at 2 000 000 cycles with a fair degree of accuracy. In this equation F represents the fatigue strength corresponding to failure at 2 000 000 cycles, and S and N represent the stress and number of cycles for failure, respectively, for a particular test. This formula has been used in this paper to determine the fatigue strength corresponding to failure at 2 000 000 cycles from tests in which failure occurred at other than 2 000 000 cycles even though it is known that the results may be somewhat in error. The actual stress and the actual number of cycles for failure are also reported.

III. RESULTS OF TESTS

5. *Fatigue Strength of Rivets.*—The specimens of series C1 were designed to fail in the tension rivets. The angles were 6 in. x 4 in. x $\frac{9}{16}$ in. with a $2\frac{1}{8}$ in. gage in the outstanding leg. The results of the tests are given in Table 1.

Specimen C1-1 was tested on a cycle in which the total load varied from 0 to 56 500 lb., the latter corresponding to an average unit tension in the rivets of 18 000 lb. per sq. in., and a flexural stress in the angles of 46 200 lb. per sq. in., the flexural stress being computed from the total load on the basis that the action of the angle is as indicated in Fig. 4. One rivet failed at 392 000 cycles. The corresponding fatigue strength for failure at 2 000 000 cycles and expressed in terms of average tension in the rivets is 15 300 lb. per sq. in. If the angles had failed at this number of cycles, the fatigue strength in flexure for failure at 2 000 000 cycles would have been 39 250 lb. per sq. in. Since the angles did not fail, all that is known is that the fatigue strength of the angles was 39 250 lb. per sq. in. or more.

Specimen C1-2 was tested on a cycle in which the load varied from 0 to 47 100 lb., the latter corresponding to an average unit tension on the rivets of 15 000 lb. per sq. in. and a flexural stress in the outstanding leg of the angle of 39 000 lb. per sq. in. The angle failed in flexure at 2 305 500 cycles. If the rivets had also failed at this time, the fatigue strength corresponding to failure at 2 000 000 cycles would have been 15 200 lb. per sq. in. for the rivets, and 39 560 lb. per sq. in. for the angles. But, since no rivets failed, all that can be said is that the fatigue strength of the rivets was at least equal to 15 200 lb. per sq. in.

*University of Illinois, Engineering Experiment Station Bulletins No. 124, p. 92 and No. 302, p. 111.

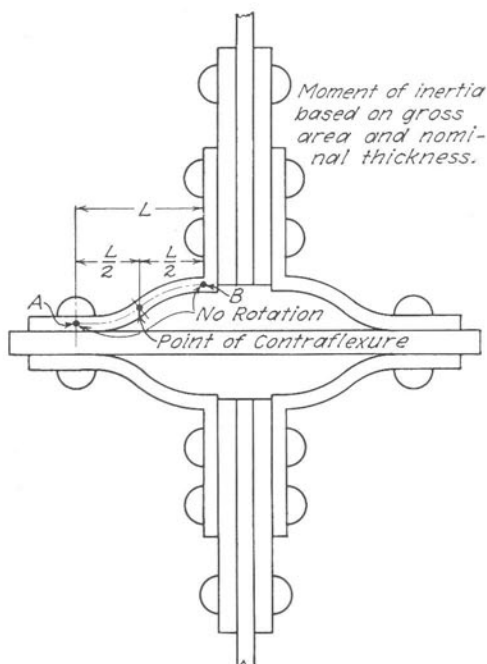


FIG. 4. ASSUMED ACTION OF ANGLES USED IN COMPUTING FLEXURAL STRESS AND DEFLECTION

Specimen C1-3 was tested on a cycle in which the maximum load corresponded to an average tension in the rivets of 16 000 lb. per sq. in. No failure had occurred at 3 245 000 cycles, and all that can be said is that the fatigue strength was somewhat greater than 16 800 lb. per sq. in. for the rivets, and greater than 43 560 lb. per sq. in. for the angles.

The specimens of series C2 also were designed to fail in the rivets. They differed from the specimens of series C1 only in that the angles were thicker. The results of the tests are also given in Table 1.

All specimens failed in the rivets, and the values of the fatigue strength corresponding to failure at 2 000 000 cycles, in lb. per sq. in. average tension in the rivets, were 18 000, 20 800, and 20 450 for C2-1, C2-2, and C2-3, respectively.

The values of the tensile stress in the rivets given in column 2 of Table 1 were obtained by dividing the maximum total load during the cycle by the nominal area of the 1-in. rivets. This method of expressing the stress has been used because it is the method used by structural engineers in designing. There are several influences, however,

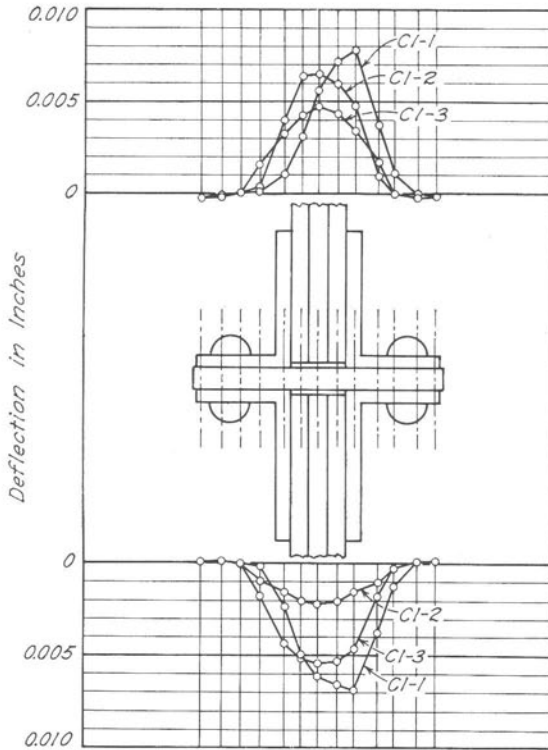


FIG. 5. DEFLECTION OF ANGLES DUE TO LOAD CAUSING TENSION IN RIVETS; SERIES C1

which cause the values thus obtained to vary greatly from the true maximum values. These are discussed in the following numbered paragraphs.

(1) The deflection diagrams of Figs. 5, 6, and 7 show that the outstanding legs do actually bend in much the same manner as that shown in Fig. 1. Because of this flexure there is a pressure a at the toes of the outstanding legs of the angles, and the tension in the rivets, represented by b , must not only balance the external load but must also balance the toe pressure. In other words, the average axial tension in the rivets is greater than the external load divided by the area of the section of the rivets, because of the toe pressure. Tests by Huntington and Nielsen show that this pressure may be quite large.*

(2) Tests have shown that properly driven rivets have high tensile stresses due to cooling subsequent to driving.† In many instances these

*Unpublished manuscript of W. C. Huntington and Paul Nielsen.

†University of Illinois, Engineering Experiment Station Bulletins No. 210, p. 27 and No. 302, p. 10.

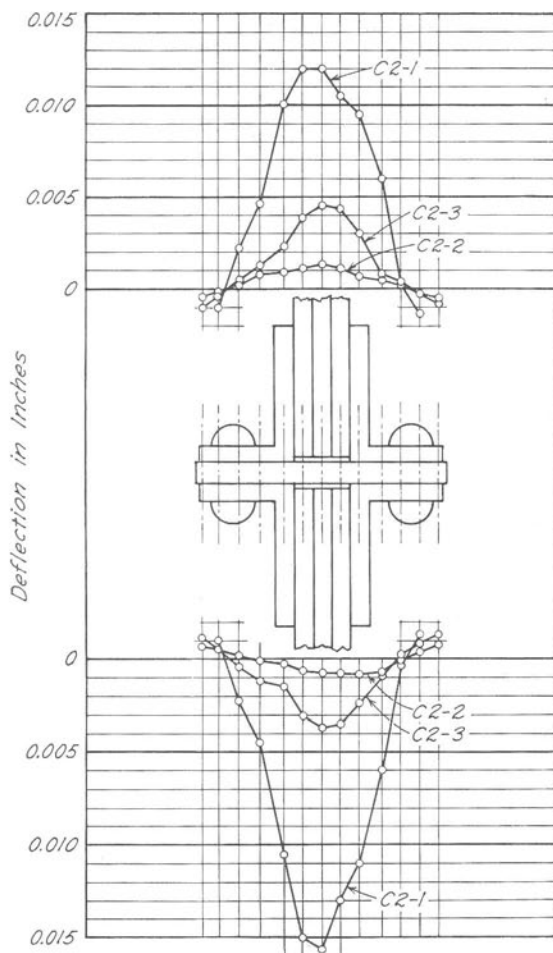


FIG. 6. DEFLECTION OF ANGLES DUE TO LOAD CAUSING TENSION IN RIVETS; SERIES C2

stresses are nearly equal to the yield point of the rivets. In the tests described in this report the change in length of the rivets during a number of load cycles was measured, the machine being cranked by hand while the readings were taken. The results, expressed in terms of stress in lb. per sq. in. necessary to produce the measured elongation, are given in columns 4 and 5 of Table 1. For specimen C2-1, a change in the external load corresponding to an average tension in the rivets of 30 000 lb. per sq. in. increased the average tension in the rivets by only 7200 lb. per sq. in. Likewise, for C2-2, a change in

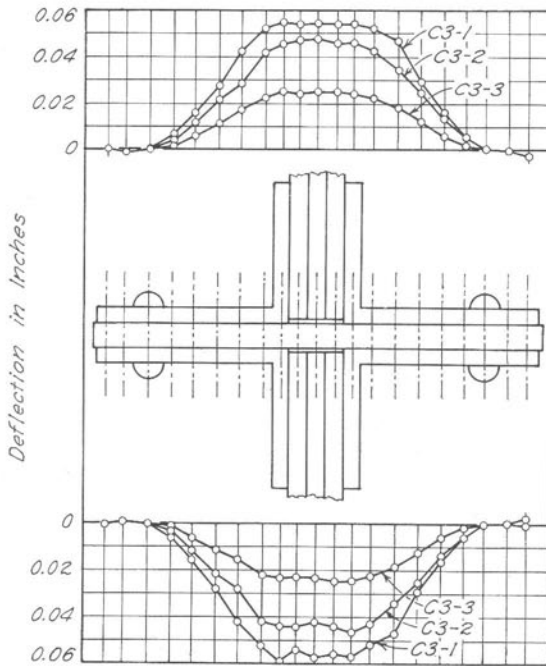


FIG. 7. DEFLECTION OF ANGLES DUE TO LOAD CAUSING TENSION IN RIVETS; SERIES C3

the external load corresponding to an average tension in the rivets of 20 000 lb. per sq. in. increased the tension in the rivets by only 1680 lb. per sq. in. and, for C2-3, a change in the external load corresponding to an average tension in the rivets of 25 000 lb. per sq. in. increased the tension in the rivets by only 1200 lb. per sq. in. It is probable, therefore, that the rivets contained an initial tension of the order of 24 000 lb. per sq. in. If that is true, then the tension in the rivets is not reduced to zero when the external load is removed, and the stress range is less, although the maximum stress may be a little greater, because of the initial tension in the rivets.

(3) The flexure of the outstanding leg of the angles, shown in Fig. 1, bends the rivet, causing a flexural stress to be set up in it. This action causes the maximum stress on a section of the rivet to exceed the average.

(4) There is an abrupt change in section where the head of the rivet joins the shank, and a change in section is a serious stress raiser. This is another influence which causes the maximum stress on a section of a rivet to greatly exceed the average.

In view of the facts presented in the preceding four paragraphs, the quotient obtained by dividing the maximum external load of the load cycle by the area of the section of the rivets bears only a very remote relation to the change in the maximum unit stress in the rivets produced by that external load. But there are so many uncertainties involved that it is impossible to arrive at any accurate value for the maximum unit stress produced.

Because of the very complex nature of the problem it is quite apparent that the fatigue strength of the tension rivets of connection angles can only be determined by tests, and that experimental results obtained from one type of connection cannot, in the present state of knowledge, be considered as applicable to connections of other types. It is not unreasonable to suppose that the stiffness of the leg of the angle and the gage of the rivets, because of their influence upon the flexure in the tension rivets, affects the fatigue strength of the tension rivets in the connection angles. For the specimens tested, the value of the fatigue strength of the tension rivets, obtained by dividing the maximum external load of the load cycle by the nominal area of the rivets, is of the order of 16 000 lb. per sq. in. for series C1 and 20 000 lb. per sq. in. for series C2. This difference may be significant and may be due to a difference in the stiffness of the angles for the two series, but additional tests are needed before this conclusion can be accepted as final. The fatigue strength, as here used, is based upon failure at 2 000 000 repetitions of a cycle in which the external load varies from 0 to a maximum tension.

6. *Fatigue Strength of Angles.*—The specimens of series C3 were designed to fail in the outstanding leg of the angles. The results of the tests are given in Table 1. The fatigue strength of the angles, based upon the unit flexural stress computed on the basis indicated in Fig. 4, is 53 630 and 48 530 lb. per sq. in. for C3-1 and C3-2, respectively. Specimen C3-3 had not failed at 3 119 400 cycles when the test was discontinued, so all that is known is that the fatigue strength for this specimen was 43 900 lb. per sq. in. or more.

Specimen C1-2 was designed to fail in the rivets but actually failed in the angle, the fatigue strength for the angle being 39 350 lb. per sq. in. The test of specimen C1-3 was discontinued at 3 245 000 cycles, although neither the angle nor the rivets showed any indication of failure. The test indicates, however, that the fatigue strength of the angles was at least 43 500 lb. per sq. in.

These tests indicated that, with flexural stresses computed on the

basis outlined in Fig. 4, the fatigue strength of the outstanding legs of the connection angles is of the order of 50 000 lb. per sq. in. for the long flexible outstanding legs of the angles of C3-1 and C3-2, and that it is approximately 40 000 lb. per sq. in. for the short stiff outstanding legs of the angles of the C1 series. Inasmuch as the fatigue strength of a rolled plate with the mill scale on the two sides, tested on a cycle in which the stress varies from zero to axial tension, is probably about 35 000 lb. per sq. in., it would seem that the method of computing the flexural stress in the outstanding legs of the angles gives values that are probably somewhat greater than the true values.

7. Deflection of Outstanding Leg of Angles.—The deflection of the outstanding legs of the angles was measured at points indicated in Fig. 3, measurements being taken at the beginning of a test and with the machine cranked by hand. The results of the tests are shown by the diagrams of Figs. 5, 6, and 7.

The curves of Fig. 5 and Fig. 7 indicate that the rivets produce a reversed bending at the toes of the angles for specimens of series C1 and C3, but the diagrams of Fig. 6 indicate that no reversed bending was produced at the toes of the angles for specimens of the C2 series. The angles were much stiffer and the rivets were more highly stressed for this latter series than for the two former ones.

In considering the deflection diagrams of Figs. 5, 6, and 7, it should be noted that the deflection was measured at the ends of the angle, and that the rivets clamping the outstanding legs of the angles are in 2 inches from the ends. For this reason it is probable that the toes of the angles are more nearly fixed at the rivets than the diagrams indicate. Moreover, the high pressure produced by the riveting machine might have caused the toe of the angles to curl up slightly, thus accounting for the negative deflection at the toe which is particularly noticeable for the C2 series. This negative deflection, however, was of the order of only 0.001 in. or 0.002 in.

At the beginning of the tests, the values of the total movement of the stringer on one side of the floor-beam relative to the one on the other side of the floor-beam were 0.0088 in., 0.0054 in., and 0.0069 in. for the specimens C1-1, C1-2 and C1-3, respectively. The values of the average unit tension in the rivets corresponding to the external loads for these specimens were 18 000, 15 000 and 16 000 lb. per sq. in., respectively. The values of the total movement of one stringer relative to the other were 0.0248 in., 0.0024 in. and 0.0044 in. for specimens C2-1, C2-2 and C2-3, respectively. The values of the average unit

TABLE 2
COMPARISON OF MEASURED AND COMPUTED MOVEMENT OF STRINGER ON ONE
SIDE OF FLOOR BEAM RELATIVE TO THAT ON OTHER SIDE,
DUE TO DEFLECTION OF CONNECTION ANGLES

Specimen Type	Load Corresponding to Fatigue Strength			Movement of One Stringer Relative to the Other in.	
	Total lb.	Equivalent Tension in Rivets lb. per sq. in.	Equivalent Flexural Stress in Angles lb. per sq. in.	Measured	Computed
C1.....	50 300	16 000*	41 500	0.0069	0.0058
C2.....	62 800	20 000*	25 800	0.0024	0.0027
C3.....	24 740	5 250	51 100*	0.0630	0.0542

*Fatigue strength of part that failed.

tension in the rivets corresponding to the external loads for these specimens were 30 000, 20 000, and 25 000 lb. per sq. in., respectively. If the average fatigue strength of the rivets is taken as 16 000 lb. per sq. in. tension for the rivets of the C1 series, and 20 000 lb. per sq. in. for the rivets of the C2 series, then the longitudinal movement of one stringer relative to the other (double the movement of each relative to the web of the floor beam), when the specimen was loaded to its fatigue strength, would be of the order of 0.0069 in. for specimens of the C1 series and 0.0024 in. for specimens of the C2 series. Apparently these movements are not of sufficient magnitude to enable the stringers and floor-beams of a railway through-truss bridge to adjust themselves to each other without causing excessive stresses. It is of interest to note also that, although the specimens of the C1 and C2 series were designed for rivet failure, the flexural stress in the angles was only slightly less than the fatigue strength. In fact one specimen, C1-2, actually failed in the angle. It is apparent, therefore, that a greater deflection could not have been obtained by using more rivets in the outstanding leg of the angles because of the probability of a failure of the angle leg.

In contrast to the small deflection of the outstanding legs of specimens of the C1 and C2 series, the values of the total movement of one stringer relative to the other were 0.1096 in., 0.0751 in. and 0.0498 in. for specimens C3-1, C3-2 and C3-3, respectively. It is to be noted that C3-3 was still intact after 3 119 400 cycles. But C3-1, loaded to produce a deflection of 0.1096 in., failed at 89 200 cycles and C3-2, loaded to produce a deflection of 0.0751 in. failed at 259 000

cycles. Being guided by the tests of C3-1, C3-2, and C3-3, it is estimated that the maximum load in the stress cycle that will cause failure in the angles at 2 000 000 is equivalent to 5250 lb. per sq. in. average tension in the rivets, and will produce a total movement of one stringer relative to the other of 0.063 in. There were no rivet failures for any of the C3 specimens.

The movement of a stringer on one side of a floor beam relative to the one on the other side, due to the deflection of the outstanding legs of the connection angles, has been computed for the load corresponding to the fatigue strength of the connection angles, and the computed and measured values are compared in Table 2. The computed values are based upon the assumption that the outstanding leg of the angle acts in the manner indicated in Fig. 4. Both the flexural and shear deformations are included.

It is of interest to note that the computed and measured values are in close agreement for all three types of specimens, the differences being 0.0011 in., 0.0003 in. and 0.0088 in. for specimen types C1, C2 and C3, respectively. The differences are of opposite sign for C1 and C2, and they are too small to be significant. The fact that, for C3, the measured value is 0.0088 in. greater (for the two angles) than the computed value indicates that there may be some rotation of the ends of the outstanding legs of the angles. Because the fatigue strength in flexure for these angles was so high (50 000 lb. per sq. in.), the flexural stress being computed on the basis indicated in Fig. 4, it would seem that the point of counterflexure was not far from the point indicated, and that the rotations at *A* and *B* must have been nearly equal. A rotation of 0.00082 radians at *A* and *B* would account for the difference between the measured and the computed values of the deflection of the angles. Considering, therefore, both the deflection and the fatigue strength in flexure of the outstanding leg of the angles, it would seem that the action of the connection angles did not differ greatly from that shown in Fig. 4 for loads not greater than the load corresponding to the fatigue strength of the connection.

8. *Variation in Rivet Tension During Cycle.*—The variation in the tension in the individual rivets during a stress cycle was measured at the beginning of each test, and at various times during the test. The average variation for all the rivets of a specimen is given in Table 1, and the variations for the individual rivets are given in Table 3. For the latter table, the upper line gives variations at the beginning of a test and the lower line the variations as determined by

TABLE 3
VARIATION IN RIVET TENSION DURING CYCLE

Specimen Number	Variation in Tension in Rivet lb. per sq. in.						Maximum Load in Terms of Average Tension in the Rivets lb. per sq. in.	Cycles to Failure in 1000's	Fatigue Strength lb. per sq. in.	
	A	B	C	D	E	F			Rivet	Angle
C1-1.....	5 900 14 900 Failed	8 400 12 100 Failed	2 800 1 900	4 200 10 400 Failed	.....	.....	18 000	..... 392.0	15 300	39 250*
C1-2.....	1 100 3 980 3 040	7 200 900 4 950 2 500	4 900 2 800 5 800 2 900	5 900 2 200 0 600	.....	.....	15 000	..... 2305.5 3245.0	15 200* 16 800*	39 560 43 563*
C2-1.....	8 060 Failed	7 600 Failed	6 800	6 340	.....	.....	30 000	..... 12.2	18 000	23 240*
C2-2.....	1 920 1 200	720 720	1 680 5 280 Failed	2 400 5 540	.....	.....	20 000	..... 2961.2	20 000	26 830*
C2-3.....	2 640 2 640	3 600 5 300	3 600 1 440	1 200 3 600 Failed	.....	.....	25 000	..... 267.7	20 450	26 410*
C3-1.....	6 750	7 200	4 800	4 700	5 350	4 800	7 420	..... 89.2	5 667*	53 630
C3-2.....	..... 0	1 870 0	3 850 4 260	1 870 2 675	1 440 1 600	..... 4 650	5 920	..... 259.0	..... 4 825*	48 530
C3-3.....	270 540	270 540	810 810	270 0	0 0	0 810	4 250	..... 3119.4	4 445*	43 900*

*Fatigue strength equals or exceeds this value; part did not fail.

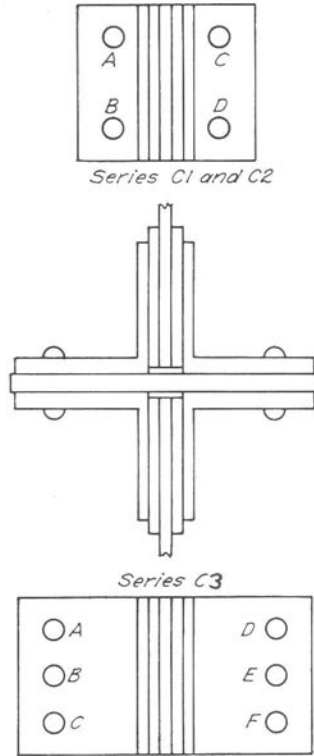


FIG. 8. SKETCH SHOWING LOCATION OF RIVETS

the last observations made during the test. Rivets that failed are so noted. The locations of the rivets by letter are given in Fig. 8.

It was hoped that a relation might be noted between the variation in the rivet tension during a cycle and the fatigue strength of the rivet, but no such relation is apparent from the data contained in Table 3.

9. *Summary.*—Because the number of tests is so small the summary is limited to statements relative to the action of the particular specimens tested.

The fatigue strength, as here used, is the maximum stress to which the part may be subjected 2 000 000 times without failure when tested on a cycle in which the total load on the specimen varied from zero to a maximum tension. The fatigue strength of the rivets is the quotient obtained by dividing the total external load that produced

failure in 2 000 000 cycles by the nominal area of the section of all tension rivets. The flexural stress in the angles was computed from the total load on the basis indicated in Fig. 4.

The results obtained were as follows:

(1) The action of the connection angles did not differ greatly from that indicated in Fig. 4.

(2) The average fatigue strength of the tension rivets was approximately 16 000 lb. per sq. in. for the three specimens of the C1 series, and 20 000 lb. per sq. in. for the three of the C2 series.

(3) The average fatigue strength in flexure of the outstanding leg of the angles of the specimens of the C3 series was of the order of 50 000 lb. per sq. in.

(4) When the specimens were loaded to their fatigue strength, the longitudinal movement of one stringer relative to the other (twice the movement of each relative to the web of the floor beam) was 0.0069 in. for the C1 series, 0.0024 in. for the C2 series and 0.063 in. for the C3 series.

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